65

WADC TECHNICAL REPORT 54-210

TRACKING PERFORMANCE AS MEASURED BY TIME CONTINUOUSLY ON TARGET

E. J. ARCHER
L. D. WYCKOFF
P. G. BROWN

UNIVERSITY OF WISCONSIN

MARCH 1954

WRIGHT AIR DEVELOPMENT CENTER

TRACKING PERFORMANCE AS MEASURED BY TIME CONTINUOUSLY ON TARGET

E. J. Archer
L. B. Wyckoff
F. O. Brown

University of Wisconsin

March 1954

Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

FOREWORD

This report describes the rationale and possible utility of a
new technique for scoring human tracking performance.

The report was prepared by the University of Wisconsin under
Contract No. AF18(600)-54. The contract was initiated under a project
identified by Research and Development Order 694-49, "Human Engineering
Research on Fire Control and Missile Control Systems." The contract
was administered by the Psychology Branch of the Aero Medical Laboratory,
Directorate of Research, Wright Air Development Center with Mr. John
W. Senders acting as project engineer.

ABSTRACT

Twenty Ss divided into two groups corresponding to fast and slow target speeds practiced on two Mast Pedestal Sight Manipulation Tests (PSMT) for five days each. In addition to the usual cumulative time-on-target per trial, a new performance measure was obtained. A Continuous-Time-On Target recorder was activated whenever the operator scored on azimuth, elevation, and range (AER) simultaneously. This recorder had 12 interval-counters which fired successively depending upon how long S continuously scored on AER. The intervals which were recorded ranged from 0.00 sec to 3.2 sec in unequal steps.

It was expected that as S became better practiced on this complex task the frequency of longer duration "hits" would increase and probably the frequency of shorter duration "hits" would decrease. In effect this would mean the mode of the frequency distribution of "hits" would shift to longer durations rather than have a uniform increase in all hit durations. These expectations were confirmed.
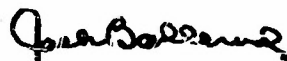
If this method of analyzing tracking performance were continued until Ss became very well practiced, it might even be possible to differentiate between stages of practice in terms of the frequency of long duration hits after cumulative times-on-target had attained an asymptote. After five days the AER scores had not reached an asymptote. Such knowledge could be of relevance in the design of gun laying computers.

Although no attempt was made to alter the characteristics of the PSMT units, except to vary the speed of targets, it seems reasonable to suppose that the continuous-time-on-target method of analyzing tracking performance could provide a more useful method for evaluating the design of gunnery equipment since in this method frequencies of hits of given duration will be governed by man-machine periodicities.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

JACK BOLLERUD
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Directorate of Research

CONTENTS

INTRODUCTION

One of the most common measures of tracking performance on experimental or training devices is either total or percentage of "time-on-target". This measure is probably used for the very good reason that it is easy to obtain. The tracking device must be designed so that a signal is produced when S is on target, but beyond this no special devices need be attached to the target generator or cursor to provide quantitative comparisons or graphic records. However, it is recognized that much potentially valuable information about performance is lost in this way. One of the most important shortcomings of a cumulative time-on-target score is that it does not reveal differences in frequency and duration of "hits". From a given total time-on-target score, one can not tell whether S made a large number of relatively brief hits or a smaller number of longer hits. This information may be important for various reasons:

1. A more detailed account of the distribution of duration of hits might show improvement resulting from improved equipment or training procedures which would not appear if only cumulative time were recorded.

2. Information regarding duration of hits may be critical in the design of computers, since a given computer generally requires a certain minimum time to be activated.

2. Additional information may make possible a better understanding of the nature of tracking behavior, which would ultimately lead to improved equipment and training procedures.

4. Such information might provide more adequate "knowledge of results" to inform S of improvement or specific kinds of difficulties.

Direct measurement of distribution of duration of hits requires the addition of some specialized recording equipment, but is still relatively easy to implement. Any system used for detecting when S is "on target" which provides a cumulative time-on-target record is equally effective for this purpose, and again no quantitative comparison of cursor and target positions is necessary.

In the present study, direct records of the distributions of duration of hits on the Mast modification of the Pedestal Sight Manipulation Test (PSMT) were obtained. Subjects were tested over a period of five days at one of two different target speeds. The objective was to obtain records of time-continuously-on-target frequency distributions at different stages of practice and on tasks of different difficulty, to discover the general nature of these distributions, and to examine the influence of practice and target speed. More specifically, we were interested in analyzing the type of shift in the distribution, if any, that occurred with practice.

PROCEDURE

Apparatus. The apparatus consisted of two Mast PSMT units and a specialized recording unit, Continuous-Time-On-Target recorder (CTOT), which recorded the distribution of duration of hits. This recording unit was connected to one of two PSMT units, and was activated whenever S was "on target" in azimuth, elevation, and range simultaneously. The recording unit consisted of a bank of 12 electronic timers and 12 associated counters. When the unit was activated the timing cycle of all timers was started. When the cycle of any given timer was completed the associated counter was activated. However, if the unit was "de-activated" before the cycle of a given timer was completed the counter was not activated and the timer was reset. Thus the counter associated with a given timer registered the number of hits with a duration equal to or greater than the interval of that timer. The 12 timers were set for the following intervals: 0, .05, .1, .2, .3, .4, .6, .8, 1.2, 1.6, 2.0, and 3.2 sec. A Standard Electric Clock reading in 1/100ths of a second was built into the unit and could be connected to the individual timers through a selector switch for purposes of calibration. The calibration of each timer was checked daily during the experiment. The unit was quite stable and needed but minor calibration adjustments during the course of several months.

Subjects. The Ss were 20 male University of Wisconsin students who were paid for serving at the rate of eighty-five cents per hour. These men were randomly assigned to one of four sub-groups, and served for five days each.

Design. All Ss were given practice on one of the two PSMT units for five daily sessions, each session consisting of eight trials of eight attacks each. The Ss were randomly assigned to two groups and each group was run at one of two target speeds. These speeds required angular velocities of 18.75°/sec. and 12.5°/sec., respectively, (4.8 sec/attack and 7.2 sec./attack). Half of the Ss in each group practiced on each of the PSMT units. In all other respects, with the exception of speed, the target paths were identical for the two groups. The target paths consisted of a predetermined sequence of eight different attacks starting alternately from the right and left of the screen. All eight possible attacks occurred on every trial, and these attacks were presented in four different orders, after which the series was repeated. Between each trial of eight attacks S had a 1-min. rest, except between trials 4 and 5 when a 5-min. rest was given.

On the PSMT an attack is the apparent flight of what looks like an interceptor on a pursuit course. The Ss were instructed to keep the center dot of a projected reticle on the nose of the plane and to adjust the ring of dots to be equal to the wing span of the plane. When these positions were maintained simultaneously the continuous-time-on-target recorder was activated. A margin of error was permitted S since the scoring zone was ± 10 mils on both the azimuth and elevation dimensions and ± 5 mils on the range dimension. In addition to the AER tracking-time analysis, total time-on-target scores for azimuth (A), elevation (E), range (R), simultaneous azimuth, elevation, and range (AER), and simultaneous azimuth and elevation (AE) were obtained.

RESULTS

The readings on a given counter of the CTOT recorder represented the number of hits of that duration or more. Subtraction of readings on successive counters yielded the number of hits which had a duration between the two timer-counters. For example, the number of hits of .3 sec. or more, minus the number of hits of .4 sec. or more gives the number of hits between .3 and .4 sec. The number of hits within each of the sub-intervals was computed in this way for each of the daily sessions.

The density of hits within each interval was computed as the number of hits divided by the interval size in 1/100ths of a second. A rationale of this computational procedure will be found in the Appendix. This step was necessary to correct for the inequality of the lengths of the intervals between counters. Table 1 gives the mean density for each interval for each

TABLE I

Density of Hits Within Each Interval. Density Is Defined as the Number of Hits During One Daily Session Divided by the Interval Size in 1/100th of a Second. Duration Is Given as the Mid-Point of the Interval.

Group	Day	Duration in Seconds										
		.025	.075	.15	.25	.3	.50	.70	1.0	1.4	1.8	2.6
	1	3.78	16.60	5.80	3.24	1.58	.965	.360	.182	.075	.020	.0033
	2	3.34	14.00	6.78	4.40	2.19	1.825	.735	.255	.195	.035	.0092
Slow	3	2.46	11.12	7.00	5.05	2.18	2.300	.935	.487	.220	.100	.0200
	4	2.64	8.78	5.57	4.54	2.01	1.850	1.005	.542	.330	.157	.0300
	5	2.80	11.90	6.20	4.70	2.23	2.050	1.100	.560	.270	.200	.0300
	1	4.24	13.70	3.16	1.18	.33	.225	.025	.0075	.0025		
	2	4.02	15.84	4.02	1.88	.70	.315	.065	.010			
Fast	3	4.36	18.52	5.36	2.91	1.19	.685	.180	.050	.012		
	4	4.46	19.30	6.22	3.66	1.70	.91	.260	.055	.010	.0075	
	5	4.92	14.90	6.45	3.97	1.56	1.16	.34	.075	.015	.0025	

of the five days.

Figs. 1 and 2 show the density as a function of duration of hits on the first and last days for the two groups. These graphs are divided into two

Figure 1. Density for the first and fifth days for the Fast Target
Group as a function of duration of hits. Density represents the
mean frequency of hits per 1/100th second of interval for eight
trials. The scale in the later portion of the graph is multiplied
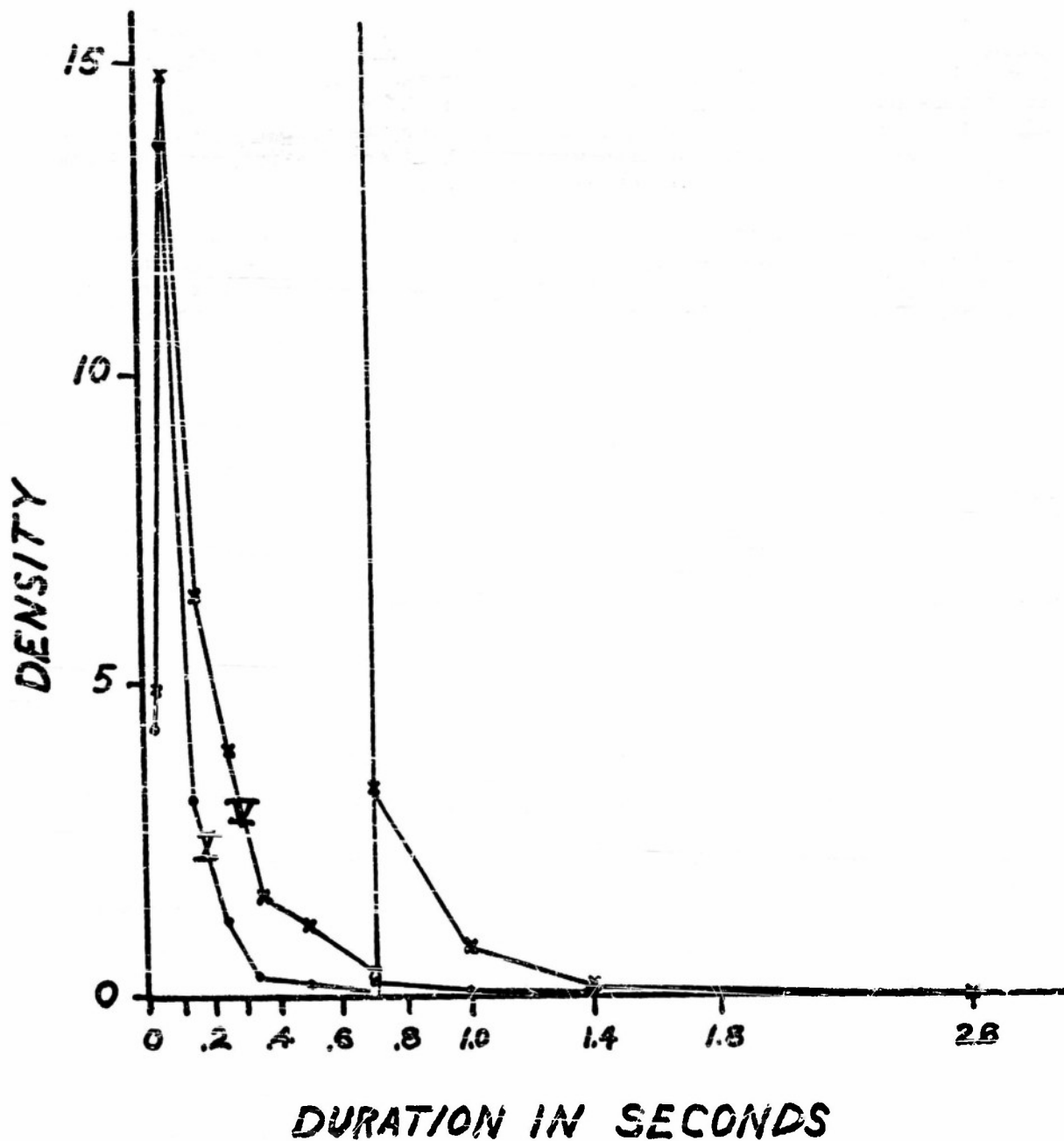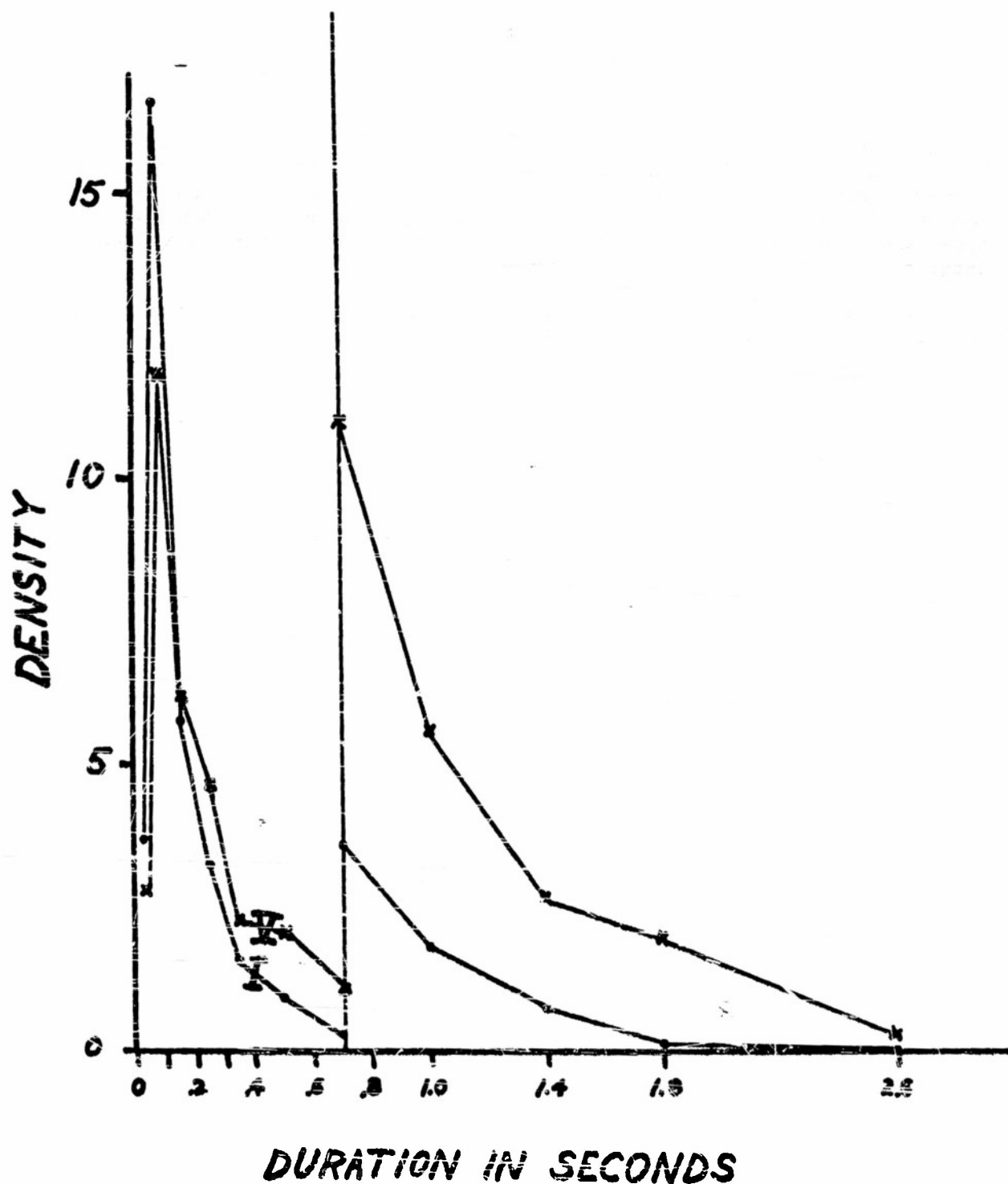by ten for the sake of clarity.

Figure 2. Density for the first and fifth days for the Slow Target Group as a function of duration of hits. Density represents the mean frequency of hits per 1/100th of a second of interval for eight trials. The scale in the later portion of the graph is multiplied by ten for the sake of clarity.

parts with the second portion plotted on a scale ten times as large as the first so that the relative positions of the tails of the curves would be visible. A test of the significance of the shift in densities at different durations was made for both speeds. In both cases the change was highly significant (p .0001). A chi-square of 471.37 with 32 $\underline{df}$ was obtained for the slow speed and a chi-square of 419.15 with 24 $\underline{df}$ was obtained for the fast speed data.

As another method of showing the relationship between groups the common log of the density was computed for each interval. The results are presented in Table 2 and are presented graphically for day 1, 3, and 5 in Figs. 3 and 4.

TABLE II

Common Log of the Density Within Each Interval.

Group	Day	Duration in Seconds										
		.025	.075	.15	.25	.35	.50	.70	1.0	1.4	1.8	2.6
	1	.58	1.22	.76	.51	.20	1.96	1.56	1.26	2.87	2.30	3.52
	2	.52	1.15	.83	.64	.34	.26	1.87	1.41	1.29	2.54	3.96
Slow	3	.39	1.05	.85	.70	.34	.36	1.97	1.69	1.34	1.00	2.30
	4	.42	.94	.75	.66	.30	.27	.00	1.73	1.52	1.20	2.48
	5	.45	1.08	.79	.67	.35	.31	.04	1.75	1.43	1.30	2.48
	1	.63	1.14	.50	.07	1.52	1.35	2.40	3.87	3.40		
	2	.60	1.20	.60	.25	1.85	1.49	2.81	2.00			
Fast	3	.64	1.27	.73	.46	.07	1.84	1.25	2.70	2.10		
	4	.65	1.28	.79	.56	.23	1.96	1.41	2.74	2.00	3.87	
	5	.69	1.17	.81	.60	.19	.07	1.53	2.87	2.17	3.40	

In the interpretation of these data* it is interesting to consider not only the number of hits of a given duration but also the time accounted for

---

*Additional data of cumulative time-on-target and its analysis is presented in the Appendix. Table 1a shows the progressive increase in performance during practice and Table 2a is analysis of variance of this data.
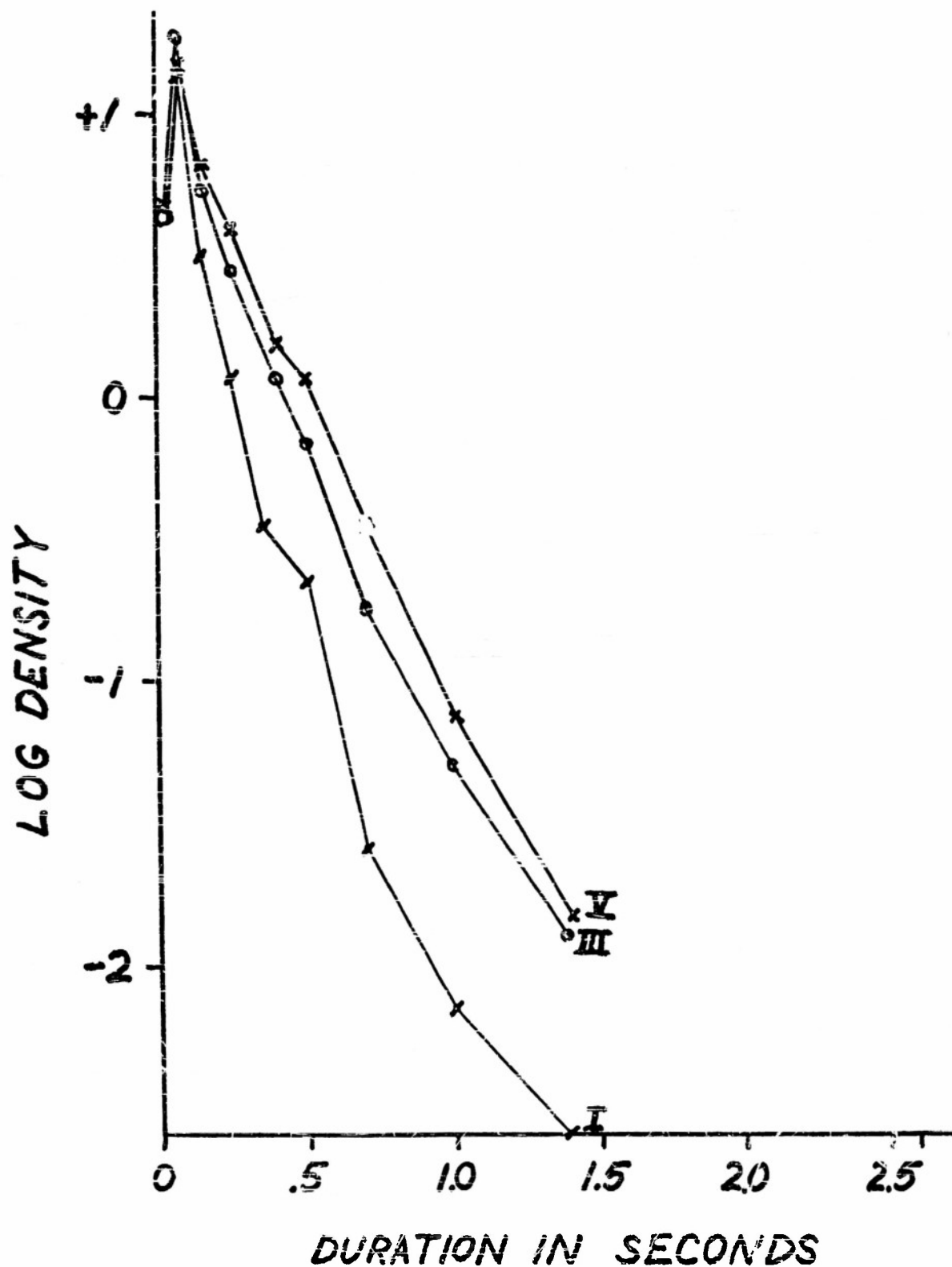
Figure 3. Log density for the first, third, and fifth days as a function of duration of hits for the Fast Target Group. Common logarithms were used.
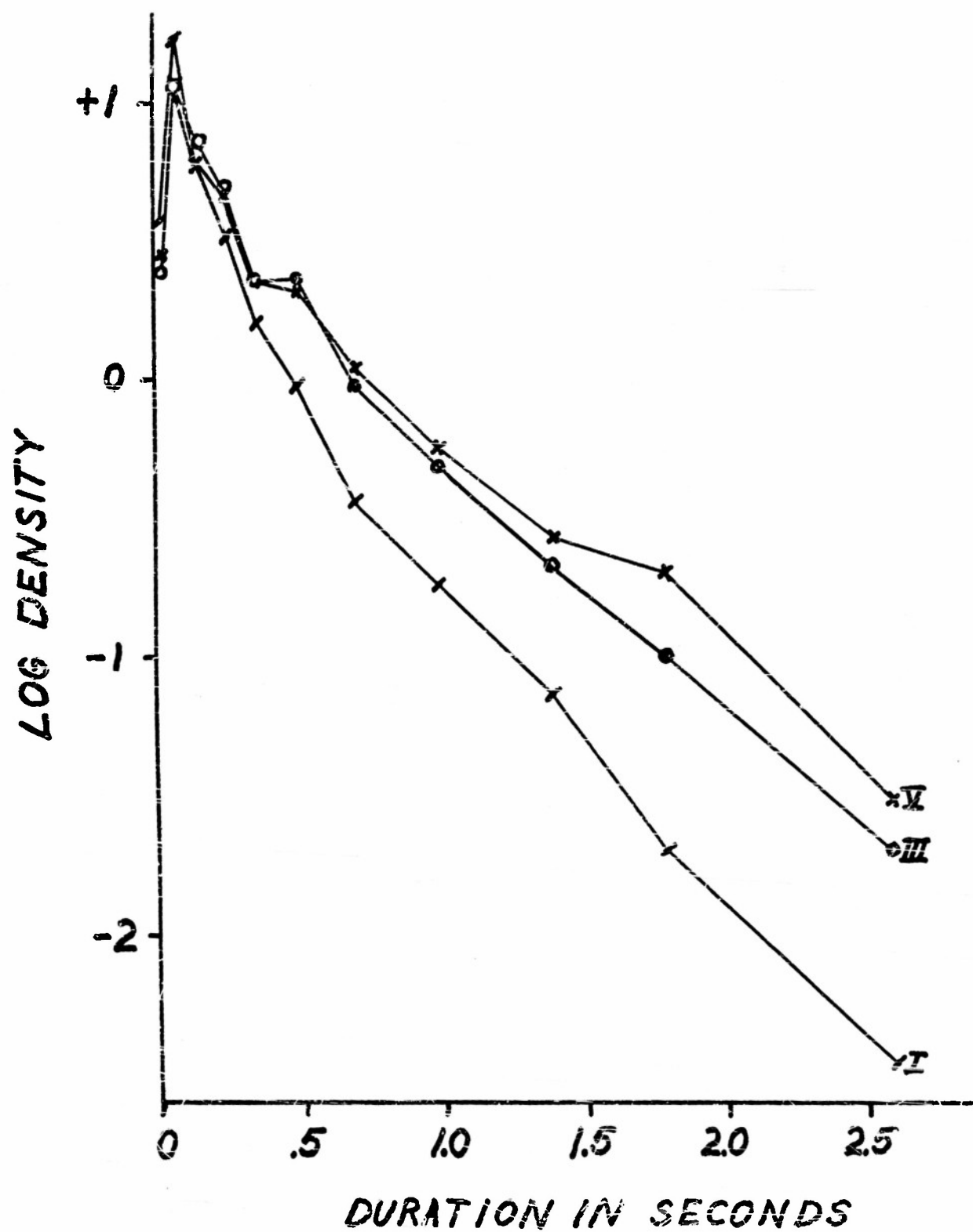
Figure 4. Log density for the first, third and fifth days as a function of duration of hits for the Slow Target Group. Common logarithms were used.

by these hits. One long hit accounts for much more time than one short hit. A time-density score was computed as the density of hits within an interval multiplied by the duration represented by that interval. In the computation of the time-density scores it was necessary to make a correction for a source of error which is similar to the grouping error sometimes encountered in statistical tabulations. Details of this correction procedure are given in the Appendix. The corrected time-density scores are presented in Table 3 and are presented graphically in Figs. 5 and 6.

TABLE III

Time-Density. Time-Density Represents the Time Accounted for by Hits Within

Each 1/100th Second Interval; Computed as Density Multiplied by Duration Cor-

rected for Grouping Error.

Group	Day	.025	.075	.15	.25	.35	.50	.70	1.0	1.4	1.8	2.6
						Duration in Seconds						
Slow	1	.95	1.24	.87	.81	.55	.465	.283	.183	.105	.036	.0086
	2	.84	1.05	1.02	1.10	.77	.855	.578	.255	.273	.063	.0250
	3	.62	.83	1.05	1.26	.76	1.045	.740	.488	.308	.180	.0520
	4	.66	.66	.84	1.13	.70	.875	.735	.543	.462	.283	.0780
	5	.70	.89	.93	1.17	.78	.965	.818	.560	.378	.360	.0780
Fast	1	.106	1.03	.474	.295	.115	.108	.037	.0075	.0035	0	
	2	.100	1.19	.602	.470	.245	.168	.061	.0100	0	0	
	3	.109	1.37	.655	.727	.416	.345	.161	.0500	.0175	0	
	4	.111	1.45	.934	.915	.595	.472	.223	.0550	.0140	.0130	
	5	.123	1.12	.968	.995	.546	.564	.272	.0750	.0210	.0045	

DISCUSSION

The following observations may be made from inspection of the obtained data:

1. General shape of the density distributions. The highest density of

Figure 5. Time-Density as a function of duration of hits for each of five days for the Fast Target Group. Time-Density represents the mean time accounted for by hits within each 1/10th sec. of interval and equals the density times the duration corrected for grouping. The first point was approximately the same for all days and is shown as a solid circle.
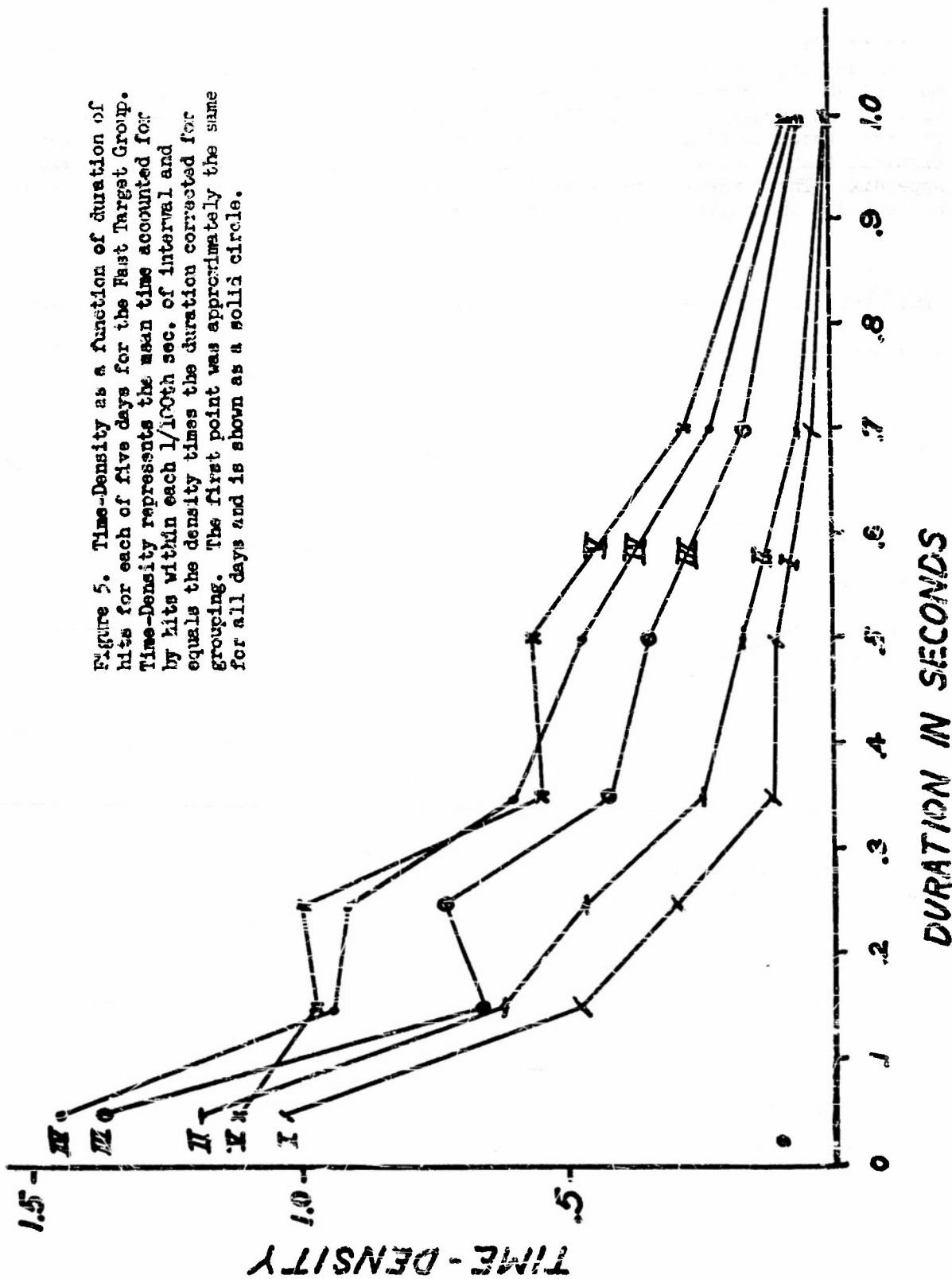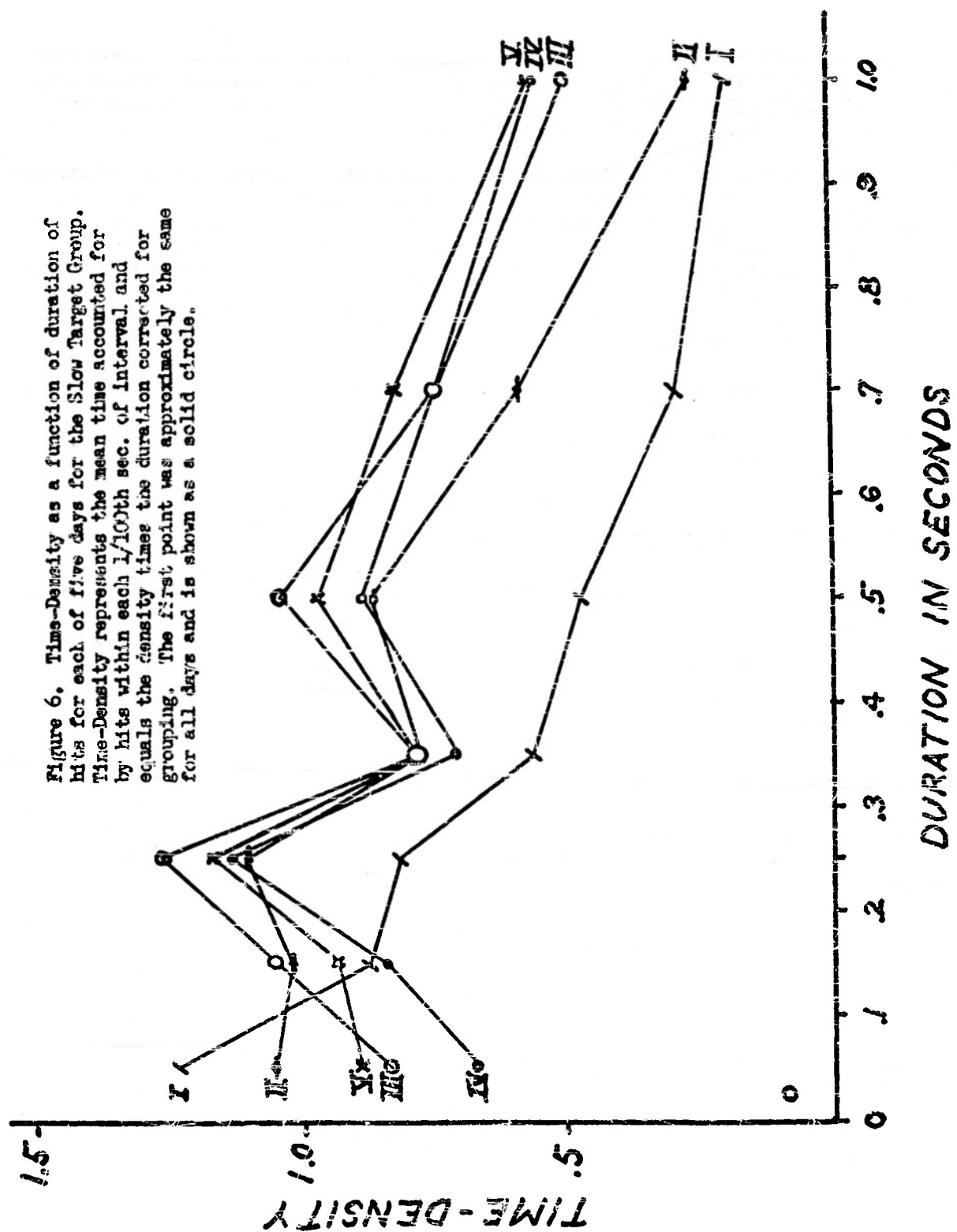
DURATION IN SECONDS

TIME - DENSITY

Figure 6. Time-Density as a function of duration of hits for each of five days for the Slow Target Group. Time-Density represents the mean time accounted for by hits within each 1/10th sec. of interval and equals the density times the duration corrected for grouping. The first point was approximately the same for all days and is shown as a solid circle.

DURATION IN SECONDS

TIME-DENSITY

hits for both groups at all stages of practice is found in the neighborhood of .075 sec. The density for longer and shorter durations is considerably lower. As duration increases beyond .075 sec. the density decreases uniformly in a negatively accelerated curve.

2. Effects of practice. Practice has a marked effect on the distribution curves. Various aspects of the effects of practice are shown by the different presentations of the curves. From the density tables and curves we observe that densities tend to increase with practice at all except the shortest durations. In these very short intervals there appears to be some tendency toward a decrease in density with practice, but this effect is not entirely consistent. The increase in density is most readily observed in the middle of the distribution.

In the interpretation of the log density data we must keep in mind that this transformation tends to minimize differences between high values and amplify differences between lower values. In effect, differences between curves represent ratios of one value to another. When we consider ratios in this way, the differences between curves at the shorter durations appear to be insignificant. The curves diverge so that the greatest differences are found at the longest durations. This uniform divergence of the curves may be contrasted with the apparent convergence of the density curves at the longest intervals. This comparison indicates that the absolute difference between curves becomes smaller as all curves approach zero density with increasing duration, but that the ratio between the curves continues to increase throughout the range of the available data. It is also of interest to note that the log curves approach linearity over a considerable portion of the distribution. This observation may have some relevance for future theoretical interpretations. It suggests that the probability of a hit is a logarithmic function of the duration of that hit.

Both the density and log density curves tend to obscure irregularities in the obtained distributions. The wide range of the density scores forces us to use a crude scale in plotting the curves, while the log transformation tends to minimize differences between relatively high values of the variable. The time-density curves on the other hand bring out certain interesting irregularities. In particular, we observe peaks in the time-density at the .25 and .50 sec. intervals with a distinct dip between these points at .35 sec. These features appear in the distributions for all of the last four days in the slow speed group. There is also some indication of a similar tendency on the last day in the fast speed group. The consistency with which these features appear indicates that something more than chance fluctuations are probably involved. The peaks would seem to indicate that a periodicity of some kind is present in the Ss performance. The frequency of this assumed periodicity appears to be unaffected by target speed. Quite possibly it is related to the natural frequencies of the man-machine combination. Additional experimentation would be necessary before a more detailed interpretation could be made.

In general we observe that the form of the distribution changes in two different ways as practice is increased. First, the density at longer intervals tends to increase while the density at shorter intervals is affected only slightly. Thus, the rate of decline or the negative slope of the distribution curve decreases with practice. Second, a periodicity in the distribution is not apparent early in practice and tends to become more marked as practice is increased.

3. Effects of target speed. In many respects a decrease in target speed has the same effect as an increase in practice. In particular, decreasing the target speed tends to increase the density of hits at the longer intervals, but has very little effect on the density for the shorter intervals. It is interesting to note that if the curves for the two speeds were superimposed they would almost coincide at the short durations. Also the tendency for the periodicity in the time-density curves to appear seems to be increased either by decreasing the speed or by increasing amount of practice.

CONCLUSIONS

Examination of the frequency distributions of continuous time-on-target, and the influence of practice and target speed on these distributions reveals certain characteristics of performance which would not be evident from cumulative time scores. Further experimentation relating to the present finding of a systematic deviation of the frequency distribution from a smooth curve would undoubtedly be useful in the determination of equipment specifications. The observed changes in characteristics of the distribution with practice might lead to improved scoring systems on training devices. Such information may also lead to a better comprehension of the nature of tracking performance and thus may implement overall improvements in sighting equipment. It should be emphasized that the present findings pertain to performance on a specific task under certain limited conditions and that further experimentation under a greater variety of conditions would be necessary to establish the generality of the findings.

Interpretation of density scores, and correction for grouping error for time-density scores. The CTOT recorder tabulates each bit as falling within one of several intervals. The frequency of hits within a given interval may be considered as the area under a frequency distribution curve within the interval. This area will, of course, depend in part on the interval size. Hence if the frequencies are to be used as an indication of the height of the distribution curve the interval size must be taken into account. This was done by dividing each frequency by the interval size expressed in 1/100ths of a second to yield a number which was called the density. The density may be interpreted by considering each interval as consisting of a number of sub-intervals of .01 sec. each. The density then represents the average number of hits in each of these sub-intervals. The density for a particular interval may be taken as the height of a distribution function at the mid-point of the interval. In using density in this way we do not assume that hits within an interval are evenly distributed through the interval, but rather that the distribution function is approximately linear within the interval, which is probably a safe assumption since the intervals are relative small in the portion of the curve where density is changing most rapidly.

Now let us consider the problem of estimating the time-density, or average amount of time accounted for by hits within each sub-interval (again using sub-intervals of .01 sec.). A rough estimate may be obtained by multiplying the density by the mid-point of the interval. However, this estimate will be accurate only if hits are symmetrically distributed within the interval. If, on the other hand, a majority of hits were actually in the lower end of the interval, we will obtain an unduly high value by using the above estimate. It can be shown that if the distribution function is approximately linear within the interval and has a slope of m the error introduced by this method is equal to $mi^2/12$, where i is the interval size. Thus the error would tend to increase rapidly as the interval size was increased.

In the present analysis the comparison of time-density between the .3 to .4, .4 to .6, and .6 to .8 intervals turned out to be of particular interest, and thus the possible error introduced by the differences in interval size became critical. The use of the correction factor $mi^2/12$ was not convenient because the slope of the distribution function could not be evaluated readily. As an alternative the longer intervals were divided into sub-intervals of .1 sec. and the density within each sub-interval was estimated graphically by linear interpolation on a magnified density curve. Time-density was then obtained by multiplying the density of each sub-interval by its mid-point, and finally the time-density for the intervals were taken as the mean of the time-density of the component sub-intervals. In this way, all time-density values in the critical region between .1 and .8 sec. were based on estimates for equal intervals of .1 sec. each. Thus the major source of distortion in the comparison of time-densities for unequal intervals was compensated.

TABLE I A

Mean Per Cent AER Scores for Two Speeds and Five Days. Each Value is the

Mean for 10 Ss

	Day				
	1	2	3	4	5
Slow Speed	16.56	23.50	29.54	30.96	33.01
Fast Speed	9.78	12.55	18.30	22.04	23.77

TABLE II A

Analysis of Variance of Cumulative Time-On-Target, Simultaneous AER Scores

Source	df	Mean Square	F
Speeds (Fast vs. Slow)	1	118,500.83	18.71**
PSMT Units (I vs. II)	1	17,726.26	2.79
PSMT x Speed	1	6,155.98	- - -
Ss / Groups	16	6,365.79*	4.95**
Days	4	11,205.83	8.78**
Days x Speeds	4	393.65	- - -
Days x PSMT	4	437.90	- - -
Days x Speed x PSMT	4	543.33	- - -
Ss x Days / Groups	64	1,275.76*	
Total	99		

* These variance estimates had a heterogeneity which could not be removed
with any rational transformation.

** In spite of the heterogeneity of variance of the error terms, it seems
reasonable to regard these F-ratios as significant since each is beyond
the 0.001 level of confidence.